REMOTE SENSING SPECTROSCOPY FOR THE POLAR REGIONS OF MARS. G. B. Hansen, Hawaii Institute of Geophysics and Planetology, SOEST, University of Hawaii, 2525 Correa Road, Honolulu, HI 96822 ghansen@pgd.hawaii.edu.

Introduction: Orbital spectral measurements of the volatile (CO_2, H_2O) polar caps of Mars can potentially answer many questions about the current climate, and the inventory and transport of volatiles and dust. These, in turn, can address questions related to past and future climates and the ultimate reservoir sizes for volatiles. The observations in the polar night require thermal infrared or active instruments (that provide their own illumination). However, the most diagnostic bands for both CO_2 and H_2O occur in the solar reflected wavelengths <5 µm and are easiest to measure after spring sunrise.

Background and Rationale: A significant fraction of the ~6 mbar CO_2 atmosphere of Mars condenses onto the winter polar regions each year. This process brings into and releases from the polar latitudes significant, but largely unknown amounts of dust and water ice. If the net balance of these materials is positive, they can accumulate in perennial water ice and dust polar caps such as are observed in the summer north pole [1]. Using summer surface temperatures, however, it has been determined that the exposed south residual cap appears to remain covered by CO_2 [2, 3]. In addition to net accumulation, the dust and water ice added to the seasonal CO_2 cap have potentially large effects on the net radiative balance during condensation and sublimation [4], and hence on interannual atmospheric pressure variations and on the net accumulation of CO_2 such that it can last throughout the summer. Orbital spectra of the polar caps can potentially measure the concentration of dust and water ice in the optical surface and constrain the dust and water ice fluxes and determine the radiative energy balance. A determination of the dust concentration in the summer north cap could provide a highly valuable constraint on the important water-to-dust ratio [5] and therefore the water reservoir capacity of the perennial cap [6]. Estimates of the typical surface deposit grain sizes can also be made; they should be strongly related to measurable properties of the surface such as the thermal inertia.

Instrumental Requirements:

Thermal: Thermal radiation from the winter poles is more or less restricted to wavelengths longer than 10 µm, depending on instrument signal-to-noise (S/N). Although significant radiation continues to >200 µm, it si unclear whether any significant information can be extracted from λ>50–60 µm (see, however, [7]). Although dust and CO_2 ice have strong spectral contrast in this region, the emissivity of surface water ice typically varies by only <5% except for the smallest grain sizes. As such it is very difficult to accurately analyze water ice grain sizes or dust mixing ratios using only thermal spectra, even if the temperatures are warm enough that spectra are useful to ~7 µm. For the purposes of studying the surface properties, spectral resolving powers ($R=\lambda/\Delta\lambda$) ≤100 are more than adequate, but the optimal separation of atmospheric gas and aerosol signals from a top-of-atmosphere spectrum may well require higher values.

Solar reflected: In the visible and near-infrared wavelengths, all the polar materials have significant and contrasting optical properties, so remote sensing of both mixing ratios and microphysical state is very feasible. For $0.3<\lambda<1$ µm, both ices are bright and white, while dust is dark and red. In the infrared both ices have strong bands whose shape is strongly dependent on particle size while dust is mostly featureless, except for a possible 2.7-µm hydroxyl absorption. Except for the finest grain sizes, water ice is very dark >3 µm, but there is a well characterized variation of the 1- to 2.5-µm spectrum of water ice with temperature [8]. This can provide information independent of thermal measurements if the spectrum is well resolved and the grain size is <1 cm. Resolving power requirements can be quite stringent in this region. R≈100 is adequate for visible measurements, while R≈300 is needed to resolve water ice features in the infrared, and R≈5000 may be needed to fully resolve the features of CO_2 ice [9] and separate them from nearby CO_2 atmospheric bands.

Existing Data Sets:

Thermal: The substantial data sets are (1) the Mariner 7 Infrared Spectrometer (IRS), measuring 4–14.3 µm, R≈100 (2) the Mariner 9 high-resolution (R~500) infrared interferometer (IRIS), measuring 5–50 µm, and (3) the Viking Orbiter 1 and 2 Infrared Thermal Mapper (IRTM) with four infrared surface-sensing broad-band channels covering 6–25+ µm. Mariner 7 was a flyby, and IRS provides only a handful of spectra of the south seasonal polar cap in the spring, but these are among the highest S/N measurements available, especially in the wavelengths 6–8 µm. The IRIS was intended for atmospheric studies and had a large field of view and low S/N; its observations of the polar regions are limited and rarely discussed. The IRTM instruments provide infrared coverage at generally high spatial resolution over large parts of two Martian years, but the information available from the broad-band sensors is limited for several reasons. Only two of the surface channels are usable during polar night, making it, for example, impossible to distinguish between variations in grain size and variations in dust content of CO_2 frosts [10].

Solar reflected: Broad band measurements by cameras on Mariners 6, 7, and 9 and the Viking Orbiters, and the solar channel on Viking IRTM provide very limited information in the visible and near-infrared (for IRTM) range. Only the Viking cameras give us any significant narrow-band color observations, but very few polar observations were made using color filters. The infrared imaging spectrometer on the Phobos spacecraft only observed the equatorial region, but the short wave channel of the Mariner 6/7 IRS took 1.9–6 µm spectra ($R \approx 100$) of Mars during two flybys. The Mariner 7 spectra of the spring polar cap are unique and valuable [11].

Current and Planned Data Sets:

Thermal: The thermal emission spectrometer (TES) on Mars Global Surveyor (MGS) observes a similar spectral range (6.5–50 µm) as the Mariner 9 IRIS, but with a much greater spatial resolution and improved S/N, at the expense of reduced spectral resolution (by a factor of 3–6). TES has already revealed new properties of the polar caps [12], and has the potential for much more, over the planned mission of ~1 Mars year. The broad spectral features in the thermal allow for less precise analysis than is possible using the finer bands in the near infrared, but the capabilities are still vary much improved over IRTM. The infrared radiometer (PMIRR) on Mars Climate Observer (MCO), is designed for atmospheric studies, but observations of the surface are planned with broadband sensors similar to IRTM. However, PMIRR has two channels with $\lambda > 30$ µm and will be in a low orbit; it could outperform IRTM in polar studies (given sufficient S/N). The Mars 2001 infrared radiometer (THEMIS) has several narrow filters in the 6.5- to 14.5-µm region intended for mineralogical studies and is not well suited for polar observations where this region is more or less dominated by dust. The planetary Fourier spectrometer (PFS) on the ESA's Mars Express mission (2003) has a channel comparable in spectral range (5–43 µm) and field of view to IRIS, but should have much improved S/N.

Solar reflected: The imaging (~0.4–1 µm) cameras on current and future Mars missions have varying qualities. Mars Orbiter Camera (MOC) on MGS has a two-color wide-angle camera and a monochromatic narrow-angle camera, and may only be useful for determining the distribution of bright and dark regions on the poles. The color imager (MARCI) on MCO has a wide-angle, five-color camera, mainly for atmospheric observations and a narrow-angle, 10-color camera designed for color surface imaging. A camera is also being prepared for the 2001 orbiter similar to the narrow-angle MARCI camera, as well as a stereo camera for the Mars Express mission. These instruments will all potentially be able to eclipse previous color imaging of Mars, but downlink volume constraints may limit the amount of multi-color data taken. Finally, both an imaging, visible to near infrared (0.4–5.2 µm, $R \geq 100$) spectrometer (OMEGA) and the short-wave channel (1.2–5 µm, $R \approx 2500$) of PFS, will be flown on Mars Express. These instruments have the unprecedented potential of observing Mars over a very broad spectral range and at two resolutions. However, the elliptical orbit of Mars Express may limit the number and quality of observations in the polar regions.

Future Measurements: Most of the substantive studies dealing with the physical properties and energy balance of the polar caps have used Viking IRTM data [1, 3, 13, 14], but these works will find likely improvement with the spectral data needed to separate the contributions of atmosphere, water ice, dust and CO_2 ice [12]. The spring polar caps are covered by a warm atmosphere laden with aerosols, which complicate the thermal spectra to an extent that it becomes difficult to separate the surface spectrum. This task should be substantially easier using near infrared reflection spectra [11], but we must wait until 2004 for this. A synergistic study with high spatial resolution color imaging and both near and thermal infrared spectra with suitable spatial and spectral resolutions is most desirable for addressing Mars polar questions. Only the planned Mars Express mission, if it continues and is successful, appears to offer this prospect. Given the current uncertainties in project funding and hardware failures, it would seem prudent to plan another mission of this sort, if at all possible.

References:

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